JACK HOLBROOK

28. 21ST CENTURY SKILLS AND SCIENCE LEARNING ENVIRONMENTS

This chapter promotes a democratic approach to education and emphasises personal and social democratic values as well as scientific knowledge and skills. It considers the goals of science education and especially those sometimes called 21st century skills. Also included is a consideration of the attention needed to the classroom learning environment for the teaching of science, drawing attention to the teaching focus, the classroom atmosphere and the teaching approach.

LEARNING OUTCOMES

When you have worked through this chapter you should be able to:

With regard to what to teach

- Appreciate the need for science education
- Identify and recognise the importance of 21st century skills
- Associate these skills with student needs for responsible citizenship and employability
- Identify the term 'education through science' and determine its meaning

With regard to facilitating learning

- Recognise the importance of establishing a conducive learning environment
- Understand the role of the teacher in developing the learning environment
- Understand the role of support materials (modules) in establishing the learning environment
- Identify and critique classroom learning approaches

TEACHING SCIENCE FOR DEMOCRATIC SOCIETY DEVELOPMENT

A democratic picture of education sees science education being portrayed as important for all students. Less attention is paid to building a widespread knowledge background, but importance is attached to promoting a wider range of competences through science teaching and thereby enabling students to function meaningfully and responsibly in a democratic society. While thinking abilities are still recognised as important, to make sense of the science encountered in everyday life, the focus

K. S. Taber & B. Akpan (Eds.), Science Education, 385–401.

is also towards capabilities in terms of personal self-determination, especially with respect to problem-solving and social consensus making, geared to students developing skills to make reasoned decisions.

In such a focus, science content can derive from relevant contexts, related to the students' world and seeking to establish the importance of science in the day-to-day functioning of society. Thus, for example, scientific concepts behind modern materials, such as polymers, foodstuffs, medicines and different forms of energy providers, all part of everyday life, are promoted, enabling understanding from a safety, environmental or health risk point of view, and hence have a potential impact on raising the quality of life. This impact on the way of life can be perceived as being immediate – discarding versus recycling of waste, or the use of paper, rather than plastic bags – or related to the future, associated with risk awareness, pollution, global warming, derisive impacts on eating habits, poverty alleviation and environmental protection or sustainability versus non-sustainability.

Such an approach inevitably has extensive implications for the type of teaching emphasis. Learning in a societal frame is expected to build on the familiar and hence lend itself to a strong constructivist approach. Inquiry-based teaching can stimulate explorations in a student-centred manner, using materials found locally, while the conceptual areas are carefully selected to take account of the local availability of materials and familiar processes, or concerns. And, of course, student involvement is highlighted by the students playing a major role in seeking and using indigenous materials, the setting up of relevant investigations and seeking the intended explanations.

THE GOALS OF SCIENCE EDUCATION

Within a democratic orientation, a commonly stated science education goal is the achievement of scientific literacy, although there are different interpretations of its meaning. In recognition that a democratic focus for science education needs to relate to society, there is a need to interrelate science and technology. Thus, Holbrook and Rannikmae (2007) put forward scientific and technological literacy (STL) as a more appropriate focus for the goals of science education.

The scientific thrust of STL has its focus on conceptualisations of need-to-know scientific knowledge, but STL also relates to an interaction of the science with society and an awareness of the need for expert opinions, thereby introducing understanding that ordinary citizens do not need to possess. STL teaching further strives to enable students to make decisions in a democratic society, where science-based technology is playing a greater and greater role and an appreciation that while the advantages of technological developments can be great for some, it can be a major disadvantage for others. Furthermore, side-effects related to health, the sustainability of the environment, or economic concerns can become key factors in choosing the most appropriate science–driven technology. STL is seen as developing student capabilities to consider and reflect on all of these.

It is not surprising that a single, simple definition of STL is always likely to be extremely problematic. A definition intended to involve an appreciation of the nature of science, the educational development of the person and functionality in a social domain, while also stressing socio-scientific-making abilities, is (Holbrook & Rannikmae, 1997):

> *developing the ability to creatively utilise sound science knowledge in everyday life, or in a career, to solve problems, make decisions and hence improve the quality of life.*

While STL is rather nebulous, it clearly draws attention to the need for education to embrace the nature of science education (NSE) (Holbrook & Rannikmae, 2007), not simply the nature of science and hence favours the democratic approach to education. Figure 1 illustrates that the nature of science education (NSE) can be taken to be the inclusion of three major educational needs – the nature of the science, personal development and social development in an educational frame. It recognises, for example, that abilities in a range of educational goals, including socio-scientific decision-making and scientific problem-solving, are more important for enhancing true scientific literacy (Shamos, 1995), or multi-dimensional scientific literacy (Bybee, 1997) than a systematic, basic understanding of poorly related, fundamental, content knowledge.

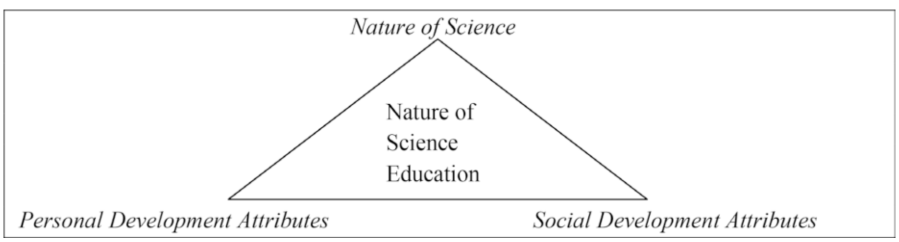

Figure 1. The three domains comprising the Nature of Science Education

EDUCATION THROUGH SCIENCE

While the nature of science education portrayed in Figure 1 recognises three key learning areas, it does not address directly the degree to which science teaching, within a specific educational focus such as for democratic development, relates to the science itself. Hence, the emphasis to be placed on promoting the nature of science, and science academic learning, versus a wider educational emphasis promoting personal and social attributes is not determined. This emphasis very much relates to the teaching focus and whether stress is placed on the scientific or the educational aspects.

It is important to stress that these directions for science education focus on the degree of emphasis rather than the exclusion, of any of the following:

- cognitive learning;
- appreciation of the subject (the nature of science);
- the development of the person to be capable of functioning in a meaningful and responsible manner;
- the development of the person, especially in terms of social values.

With the above in mind, the use of education through science emphasizes the educational learning over the science content. This contrasts with a science through education approach in which the science is the dominant aspect.

21ST CENTURY SKILLS

An emerging body of research suggests that gaining a set of broad citizenship and employability skills is an important focus in the 21st century. Such skills are seen as valuable towards becoming more responsible within society and enabling individuals to be better placed to secure a wide range of jobs in the national economy. Some business and education groups have advocated infusing specifically-identified 21st century skills into the school curriculum, and developments have taken place in this direction (Partnership for 21st Century Skills, 2008; NRC, 2010). The NRC [define for readers] put forward five broad categories or attributes – Adaptability; Complex communication/social skills; Non-routine problem- solving skills; Self-management/self-development; and System thinking. Clearly, these apply across the curriculum and not simply to a single subject area such as school science, but they tend to complement rather than oppose the 'education through science' approach introduced in the previous paragraph.

The earlier arguments have gradually focused on the expectation that gaining science knowledge and skills is not enough. There is a need also to be able to make use of the learning in science lessons, especially within society and in the workplace. This clearly favours the democratic approach to science teaching and the interrelating of the learning within science lessons with the learning taking place in other subject disciplines. It promotes the not-ion that students need to appreciate that the teaching of science in school is not only valuable in terms of forming a scientific knowledge based, but also in promoting competences to enable citizens to function in the 21st century, especially in allowing them to increase their marketability, employability and readiness for citizenship.

Nevertheless, in striving to identify the directions for success in learning, the development of students as individuals, as well as future citizens, the Melbourne Declaration on Education Goals for Young Australians (MCEETYA, 2008) identified more fully the learning that can relate to students. Linking this to 21st century needs, whether expressed by the NRC (table 1, column 2) or by teaching aspects (table 1, column 3), poses a challenge as one focuses on the personal needs and social values while the other sees employability as of much importance. Table 1 attempts to interrelate these two directions towards a new curriculum and teaching focus.

Table 1. Interrelating educationally perceived Student Needs with the promotion of 21st Century Skills

Education Goals (Melbourne Goals Declaration)	*21st Century learning skills (NRC)*	*Teaching to develop 21st Century skills) (Anderman & Sinatra, 2009)*
(a) Successful learners are those who:	• Possible related statements	• Possible related statements
(i) Develop their *capacity to learn* and play an active role in their own learning.	4.2. Develop an ability to work autonomously. 3.3. Foster creativity to generate new and innovative solutions.	1. Foster a productive learning environment. 4. Capitalizing on progressions in learning by revisiting earlier content in more depth. 6. Using assessment strategies that focus on higher order learning;
(ii) Have *essential skills* in literacy and numeracy, are creative and productive users of technology (especially ICT), as a foundation for success in all learning areas.	3.6. Acquire knowledge of how the information is linked conceptually in problem solving situations. 3.3. Foster creativity to generate new and innovative solutions. 2.5. Gain service orientation communication.	3. Developing requisite knowledge, skills, and dispositions necessary for science literacy and to support nascent science career choices. 4. Capitalizing on progressions in learning by revisiting earlier content in more depth.
(iii) Are able to *think deeply* and logically, and obtain and evaluate evidence in a disciplined way as the result of studying fundamental disciplines.	3.1. Ability to narrow the information to reach a diagnosis of the problem to be solved. 3.2. Ability to reflect on whether a problem-solving strategy is working and switch to another strategy if the current strategy is not working. 3.3. Foster creativity to generate new and innovative solutions.	3. Developing requisite knowledge, skills, and dispositions necessary for science literacy and to support nascent science career choices. 5. Promoting an inquiry and problem-based learning approach to science instruction. 6. Using assessment strategies that focus on higher order learning.

(Continued)

Table 1. (Continued)

Education Goals (Melbourne Goals Declaration)	*21st Century learning skills (NRC)*	*Teaching to develop 21st Century skills) (Anderman & Sinatra, 2009)*
(iv) Are creative, innovative and resourceful, and are able to **solve problems** in ways that draw upon a range of learning areas and disciplines.	3.1. Ability to narrow the information to reach a diagnosis of the problem to be solved. 3.2. Ability to reflect on whether a problem-solving strategy is working and switch to another strategy if the current strategy is not working. 3.3. Foster creativity to generate new and innovative solutions. 3.6. Acquire knowledge of how the information is linked conceptually in problem solving situations.	1. Fostering productive learning environments. 6. Using assessment strategies that focus on higher order learning.
(v) Are able to plan activities independently, collaborate, work in teams and communicate ideas.	4.1. Ability to work remotely, in virtual teams. 4.4. Self-monitoring.	1. Fostering productive learning environments. 6. Using assessment strategies that focus on higher order learning.
(vi) Are able to make sense of their world and think about how things have become the way they are.	1.1. Social perceptiveness, 3.4. Integrating seemingly unrelated information. 3.5. Recognize patterns not noticed by novices.	2. Promoting active engagement, based on connections to students' personal interests and career goals. 3. Developing requisite knowledge, skills, and dispositions necessary for science literacy and to support nascent science career choices. 6. Using assessment strategies that focus on higher order learning.

Education Goals (Melbourne Goals Declaration)	*21st Century learning skills (NRC)*	*Teaching to develop 21st Century skills) (Anderman & Sinatra, 2009)*
(vii) Are on a pathway towards continued success in further education, training or employment, and acquire the skills to make informed learning and employment decisions throughout their lives.	4.1. Systems analysis considering things as scientists do. 5.2. Systems decision-making.	2. Promoting active engagement, based on connections to students' personal interests and career goals. 3. Developing requisite knowledge, skills, and dispositions necessary for science literacy and to support nascent science career choices.
(viii) Are motivated to reach their full potential.	4.3. Self-motivation.	6. Using assessment strategies that focus on higher order learning.
(b) confident and creative individuals are those who:		
(i) Have a sense of self-worth, self-awareness and personal identity that enables them to manage their emotional, mental, spiritual and physical well-being – have a sense of optimism about their lives and the future.	1.2. Adaptable in handling work stress. 1.2. Ability and willingness to cope with uncertainty.	2. Promoting active engagement, based on connections to students' personal interests and career goals.
(ii) Are enterprising, show initiative and use their creative abilities.	1.3. Communicating through Instructing, 3.3. Foster creativity to generate new and innovative solutions. 4.1. Ability to work remotely, in virtual teams.	6. Using assessment strategies that focus on higher order learning.
(iii) Develop personal values and attributes such as honesty, resilience, empathy and respect for others.		

(Continued)

Table 1. (Continued)

Education Goals (Melbourne Goals Declaration)	*21st Century learning skills (NRC)*	*Teaching to develop 21st Century skills) (Anderman & Sinatra, 2009)*
(iv) Have the knowledge, skills, understanding and values to establish and maintain healthy, satisfying lives.	3.3. Foster creativity to generate new and innovative solutions.	3. Developing requisite knowledge, skills, and dispositions necessary for science literacy and to support nascent science career choices.
(v) Have the confidence and capability to pursue university or post-secondary vocational qualifications leading to rewarding and productive employment.	1.1. Ability and willingness to cope with uncertain, new, and rapidly changing conditions on the job.	2. Promoting active engagement, based on connections to students' personal interests and career goals.
(vi) Relate well to others and form and maintain healthy relationships.		
(vii) Are well prepared for their potential life roles as family, community and workforce members.	1.1. Ability and willingness to cope with uncertain, new, and rapidly changing conditions on the job. 4.5. Willingness and ability to acquire new information related to work. 4.6. Willingness and ability to acquire new skills related to work.	
(viii) Embrace opportunities, make rational and informed decisions about their own lives and accept responsibility for their own actions.	1.4. Able to be persuasive and participate in negotiation.	

Education Goals (Melbourne Goals Declaration)	*21st Century learning skills (NRC)*	*Teaching to develop 21st Century skills) (Anderman & Sinatra, 2009)*
(c) active and informed citizens are those who:		
(i) Act with moral and ethical integrity.		
(ii) Appreciate existing social, cultural, linguistic and religious diversity, and have an understanding of a country's system of government, history and culture.	2.1. Social perceptiveness.	
(iii) Understand and acknowledge the value of indigenous cultures and possess the knowledge, skills and understanding to contribute to, and benefit from, reconciliation between indigenous and non-indigenous peoples.	1.3. Adapting to different personalities, communication styles, and cultures. 2.1. Social perceptiveness.	
(iv) Are committed to national values of democracy, equity and justice, and participate in the country's civic life.	2.1. Social perceptiveness.	
(v) Are able to relate to and communicate across cultures, especially the cultures and countries of Asia.	1.3. Adapting to different personalities, communication styles, and cultures. 2.1. Social perceptiveness.	
(vi) Work for the common good, in particular sustaining and improving natural and social environments;.	2.1. Social perceptiveness, Service orientation communication.	2. Promoting active engagement, based on connections to students' personal interests and career goals.
(vii) Are responsible global and local citizens.	1.4. Physical adaptability to various indoor or outdoor work environments.	

N.B. Numbers relate to the labelling given to skills in the indicated references

LEARNING ENVIRONMENT

It is proposed that the learning environment needs to be conceived from three major perspectives:

a. The teaching focus,
b. The classroom atmosphere, and
c. The teaching approach.

a. The teaching focus is related to the degree of emphasis on the different aspects of the nature of science education. This relates to the goals of education and the perception of STL. The teaching focus thus pays attention to the emphasis placed on science conceptual learning, alongside the development of the person geared to responsible citizenship and social development. The focus is particularly geared to employability and reasoned, decision making. In turn, the focus relates to whether the democratic orientation is adopted and whether education through science is the preferred orientation.
b. Classroom atmosphere relates to the manner in which the teacher interacts with the students. The role of the teacher is thus crucial in setting the scene for the learning (the classroom atmosphere is controlled by the teacher). Where this role is effective:
   1. the classroom atmosphere promotes student motivation;
   2. student motivation is likely triggered by the teaching perceived by students as being relevant and meaningful;
   3. motivation is sustained through constructivist teaching principles and the use of student-centred learning techniques;
   4. motivation is aided by an 'education through science' approach to learning.

The aspects in the previous paragraph suggest the manner in which the teacher interacts with different students is important. There is a need for consistency and fairness so that all students feel they are being treated equally. This is not actually treating all students in the same manner, as students have different needs and hence appreciate different levels of support. Perhaps consistency and fairness is more appropriately seen in terms of supporting students with their zone of proximal development (what students are capable of achieving with the guidance and support of others, such as the teachers and/or other students). Flexibility is also seen as important in inducing student abilities. One way to give students greater flexibility is to allow them choices in portions of the course content, topics for papers, and questions for class discussion. Flexibility leads to a sense of control, which can contribute to a student's expectation of success.

As a final note on classroom atmosphere, it is much easier for students to learn when something makes sense to them and is related to one's life, interests or aspirations. Teaching at the students' pace, with multiple opportunities for student involvement clearly makes sense. Putting forward science as isolated facts, or unrelated theories can be expected to lead to memorisation and the development of poorly conceptualised learning, or even misconceptions. This does little to promote 21st century skills and enhance employability.

c. A key factor related to both classroom atmosphere and teaching approach is that the teaching of science needs to address its lack of popularity among students. This seems to be better addressed at students grade 7 and above. Top of the list in this respect is relevance of the teaching in the eyes of students.

The literature suggests that for the teaching of science subjects to be more relevant for students, there is a need for:

- student participation in the choice of social context for science learning;
- an increase in student activities and with this greater opportunities for student self-learning; related here is the need for more potential diagnostic measures of the effectiveness of the teacher;
- maximising student involvement and the important move away from teacher-centred approaches.

Table 2 summarises connections between the teaching focus, the classroom atmosphere and teaching approach.

CRITERIA FOR AN EXEMPLARY STL LEARNING ENVIRONMENT

The following criteria are put forward for STL learning environment needs. (Holbrook, 1997; Holbrook & Rannikmae, 1997).

Involve Demanding (Higher Order) Thinking Skills

Undertaking the activity is an appropriate learning exercise for the learner i.e. it provides an intellectual challenge at an appropriate level for the students. It utilizes constructivist principles – moving from information and understanding already in the possession of students, to the new learning situation. It involves analytical or judgemental thought.

Include a Communication Skill Component

Due consideration is given to enhancing a wide range of communication skills appropriate for the dissemination of scientific ideas and social values. This will involve oral (group discussion, debate, role playing), graphical, tabular, symbolic, pictorial as well as written forms.

Table 2. Interrelating the teaching focus, the classroom atmosphere and teaching approach

Teaching focus	*Classroom atmosphere*	*Teaching approach*
Selected features of science teaching	Skills/knowledge needed by teacher	
1. Teacher identifies the curriculum focus related to the intended teaching and learning.	Requires an appreciating of relevance from the students' perception and the degree of familiarity expressed by the students. Establishing prior learning, especially in a social sense.	Motivational: building on the relevance and familiarity of the initial situation. Student centred: involve student in putting forward their current learning as a base for identifying the need for further learning The planning and evidence gathering and interpretation as components of inquiry-based science education (IBSE).
2. Teacher solicits students' initial conceptions of focal phenomena; guides students to represent what they know, then links this to further instruction (new learning) based on expressed currently understanding.	Establishes prior learning of science ideas (concepts and process skills). Requires teacher's ability to construct questions or tasks that are "rich"—i.e. have potential to reveal multiple facets of student thinking about target idea. Requires *analysis of student responses* and comparison against target understanding, to make *principled judgments* about how to design further instruction.	Continues to be motivational: building on the relevance and familiarity of the initial situation. Constructivist approach building on students' identified prior knowledge and skills.

Teaching focus	*Classroom atmosphere*	*Teaching approach*
3. Teacher guides/co-constructs with students to identify deficiencies in students' scientific conceptualization, awareness, skills and other issues of relevance. Focus on deriving the need for key science learning that forms the focus for further curriculum-related teaching. Identifying the scientific question to be addressed.	Requires strategies for guiding student inputs towards relevance as a base for the further learning anticipated by the teacher Requires vision of what type of scientific question is complex enough to be meaningful, can be at least in part put forward by student and can sustain motivation related to the inquiry scientific learning to be introduced.	Continues to be motivational: building on the relevance and familiarity of the initial situation. Critical thinking by students in establishing their lack of needed knowledge and skills to conceptualise the situation from a science perspective. Self-efficacy of students to engage in putting forward the scientific question to investigate and gain new science conceptual knowledge.
4. Teacher guides students to hypothesis, plans investigations and interpret evidence as well as providing resources, scaffolding experiences relevant to answering essential student questions. Resources related to investigation could cover readings (books/ internet), technology, other tools, hands-on experimentation. Also supports *students* in deciding what other kinds of resources and experiences needed.	Requires understanding of how to help students hypothesise, plan, investigate and interpret evidence as well as undertake collaborative group work ideas and construct complex forms of meaning *across* representations (problem solving and meta-representational competence). Requires understanding of how experiments and other forms of testing providing data can be used as evidence to support solutions or explanations answering big questions.	Continues to be motivational: building on the relevance of the investigation and related science conceptualisation. Collaborative learning within peer groups. Developing or enhancing problem solving skills including safety, error identification and limitation, and recording skills. Conceptualisation of new science learning. Development of meta-cognition and meta-representation skills.

(Continued)

Table 2. (Continued)

Teaching focus	*Classroom atmosphere*	*Teaching approach*
5. Teacher supports (scaffolds and assesses) students in monitoring their own progress toward defined goals.	Requires understanding of modelling and how to foster metacognition, self-regulation in students. Requires teacher to possess a broad repertoire of formative assessments. Understands in what contexts they should be used, how they can provide both teacher and student with targeted feedback. Requires specialized discourses around questions such as: "What additional information do I need?" "How do I know we've solved the problem?" "What evidence will count as supporting an explanation?" "How do we address alternative hypotheses?"	Continues to be motivational: building on the relevance of the investigation and related science conceptualisation. Metacognition and self-regulation to ensure learning at the students' pace. Teacher and peer group scaffolding to enabling meeting more demanding challenges.
6. Teacher monitors and evaluates student understanding of science ideas and engagement in authentic scientific conceptualisations and problem solving.	Requires broad repertoire of formative assessments. Understands in what contexts they should be used, how they can provide both teacher and student with targeted feedback.	Continues to be motivational: building on the relevance of the investigation and related science conceptualisation. Metacognition and self-regulation to ensure learning at the students' pace. Teacher and peer group scaffolding to enabling meeting more demanding challenges.

Teaching focus	*Classroom atmosphere*	*Teaching approach*
7. Teacher guides students to interrelate new knowledge with existing conceptualization via techniques such as constructing concept maps. Teacher presses students to compare and integrate ideas across different representations/ disciplines, use secondary data and primary data as evidence to support explanatory models and arguments relevant to essential questions.	Requires understanding of how to weigh different forms of evidence, coordinating evidence and explanations, differentiating between theory and evidence. Requires orchestrating productive discourse by students in collaboratively evaluating solutions to problems or explanatory models. Requires understanding of the rhetorical practices of authentic science.	Continues to be motivational: building on the relevance of the investigation and related science conceptualisation. Metacognition and self-regulation to ensure learning at the students' pace. Teacher and peer group scaffolding to enabling meeting more demanding challenges.
8. Teacher guides students to interrelate the new science learning with the initial situation Interrelate the science with other social factors and determine the relative importance of the science to the familiar situation through argumentation and decision making. Teacher asks students to review the intellectual work of others in ways consistent with scientific practice and in ways that advance the thinking of others.	Requires ability to manage a "community of practice" in classroom. Needs to model discursive interactions over ideas that are appropriately challenging, based on evidence, and civil. Needs to model how one learns from feedback, how one re-considers ideas in light of input from others.	Continues to be motivational: building on the relevance of the investigation and relating the science to the initial societal situation. Metacognition and self-regulation to ensure involvement in development of argumentation skills and decision-making. Teacher and peer group scaffolding to enabling meeting more demanding challenges and reaching consensus among peers.

Include a Comprehensive Teacher's Guide

As problems, issues and concerns coming from society are often interdisciplinary in character, with the science ideas unfamiliar to the teacher, full explanations are needed to help teachers make use of the materials in a meaningful and interesting manner. The teacher's guide also needs to highlight the link between activities put forward and the outcomes expected of the teaching in terms of educational objectives. The teacher's guide needs to detail a suggested teaching strategy by which the student-centred approach is exemplified.

SUMMARY

This chapter is based on the democratic view of education, catering for all students. It sets out to introduce 21st century skills and explain appropriate science learning environments from a teaching focus, classroom atmosphere and teaching approach perspective.

FURTHER READING

Fraser, B. (2012). Classroom learning environments: Retrospect, context and prospect. In B. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *2nd international handbook of research on science education* (pp. 1191–1239). Dordrecht, Heidelberg, London & New York, NY: Springer.

National Research Council. (2009). *Exploring the intersection of science education and 21st century skills: A workshop summary*. Retrieved from http://www.nap.edu/catalog.php?record_id=12771

National Research Council. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. Retrieved from http://www.nap.edu/catalog/13398/education-for-life-and-work-developing-transferable-knowledge-and-skills

National Research Council. (2016). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. Retrieved from http://www.nap.edu/catalog/21836/science-teachers-learning-enhancing-opportunities-creating-supportive-contexts

REFERENCES

Anderman, E. M., & Sinatra, G. M. (2009). *The challenges of teaching and learning about science in the 21st century: Exploring the abilities and constraints of adolescent learners.* Paper prepared for the Workshop on Exploring the Intersection of Science Education and the Development of 21st Century Skills, National Research Council. Retrieved from http://www7.nationalacademies.org/bose/AndermanSinatra.pdf

Bybee, R. W. (1997). Towards an understanding of scientific literacy. In W. Gräber & C. Bolte (Eds.), *Scientific literacy. An international symposium*. Kiel, Germany: IPN.

Holbrook, J. (1997). Resource materials for science education reform. In KEDI: *Globalization of Science Education – moving towards worldwide science education standards* (pp. 205–213). Korea: Proceedings of the International Conference on Science Education.

Holbrook, J., & Rannikmae, M. (2007). Nature of science education for enhancing scientific literacy. *International Journal of Science Education*, *29*(11), 1347–1362.

MCEETYA Secretariat. (2008). *Melbourne declaration on educational goals for young Australians.* Australia, Carlton South, Vic. Retrieved from www.mceetya.edu.au

National Research Council (NRC). (2010). *Exploring the intersection of science education and 21st century skills: A workshop summary.* (Margaret Hilton, Rapporteur. Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education.) Washington, DC: The National Academies Press.

Shamos, M. (1995). *The myth of scientific literacy*. New Brunswick, NJ: Rutgers University Press.